50678

CORRES CONTROL
OUTGOING LTR NO

DOE ORDER# 4700.1
95RF01564

DIST	LTR	ENC
AMARAL M E		
BURLINGAME A H		
BUSBY W S		
BRANCH D B		
CARNIVAL G J		
DAVIS J G		
FERRERA D W		
FRAY R E		
GEIS J A		
GLOVER W S		
GOLAN P M		
HANNI B J		
HARMAN L K		
HEALY T J		
HEDAHL T		
HILBIG J G		
HUTCHINS N M		
JACKSON D T		
KELL R E		
KUESTER A W		
MARX G E		
McDONALD M M		
McKENNA F G		
MONTROSE J K		
MORGAN R V		
POTTER G L		
PIZZUTO V M		
RISING T L		
SANDLIN N B		
SCHWARTZ J K		
SETLOCK G H		
STEWART D L		
STIGER S G	✓	
TOBIN P M		
VOORHEIS G M		
WILSON J M		
S. A. BICKER	✓	✓
N. A. HOLSTEEN	✓	✓
M. L. HOGG	✓	✓
R. A. RANDALL	✓	✓
CORRES CONTROL	X	X
ADMN RECORD/080	✓	
TRAFFIC		✓
PATS/T130G	✓	✓

CLASSIFICATION

UCNI	
UNCLASSIFIED	✓
CONFIDENTIAL	
SECRET	

AUTHORIZED CLASSIFIER SIGNATURE

DOCUMENT CLASSIFICATION REVIEW WAIVER PER CLASSIFICATION OFFICE

IN REPLY TO RFP CC NO
0314RF95

ACTION ITEM STATUS
☐ PARTIAL/OPEN
☒ CLOSED

LTR APPROVALS

ORIG & TYPIST INITIALS
NAH/cb

EG&G ROCKY FLATS

EG&G ROCKY FLATS, INC
ROCKY FLATS PLANT P O BOX 464 GOLDEN COLORADO 80402 0464 (303) 966 7000

February 9, 1995

95-RF-01564

Jessie M Roberson
Environmental Restoration Division
DOE, RFFO

Attn Kurt Muenchow

EVALUATION OF ARSENIC IN OPERABLE UNITS (OUs) 5 AND OU6 IN COMPARISON TO BACKGROUND NO 4 - SGS-049-95

Ref J M Roberson ltr (08074) to S G Stiger, Interim Guidance on Operable Units 5 and 6 Risk Assessment Calculations, January 30, 1995

Action None required

This letter is written in response to your request for a comprehensive and exhaustive technical argument supporting the exclusion of arsenic as a Chemical of Concern (COC) in Operable Units 5 and 6 Arsenic is examined for groundwater, pond sediments, and stream sediments, but was not considered a COC in other media Also included is a spatial distribution evaluation for Arsenic on a sitewide level OU5 and OU6 risk assessments are proceeding without arsenic included as a COC until further guidance

Technical information on the arsenic issue is attached for your evaluation

Should you have any questions or concerns regarding this issue, please call Neil Holsteen, of my staff, at 966-6987

SG Stiger

S G Stiger, Director
Environmental Restoration Program Division

NAH cb

Orig and 1 cc - J M Roberson

Attachment
As Stated

cc
M N Silverman - DOE, RFFO

A-OU05-000655

DISCUSSIONS ON ARSENIC AT RFETS

During the January 25, 1995 meeting between DOE, RFFO and OUs 5 and 6 EG&G staff, DOE requested that EG&G provide technical information on the available process knowledge on arsenic usage at RFETS and an additional data evaluation for arsenic detected in OUs 5 and 6 The purpose of this letter is to provide this information

Process Knowledge

As stated in the January 31, 1995 correspondence to Kurt Muenchow, DOE/RFFO, from Ed Mast, EG&G ERPD, Letter #ECM-008-95, EG&G reviewed the *Reconstruction of Historical Rocky Flats Operations & Identification of Release Points* (CDH, 1992) and the *Historical Release Report for the Rocky Flats Plant* (EG&G, 1992) and found no discussion of arsenic being used and/or released from any of the past processes at RFETS Since then, an attempt was made to further document any possible uses of arsenic at RFETS, such as a pesticide for grasshopper control prior to the 1960s or 1970s The ERPD librarian conducted an extensive search for references to arsenic in the sitewide databases A majority of these references discussed arsenic as a sample analyte or within a general discussion of chemicals One reference to the use of arsenic was as a chemical standard for the atomic absorption process in Building 771 However, no references were found indicating that arsenic was used in any large quantities at RFETS Thus, it is unlikely that the arsenic detected in OUs 5 and 6 sediments results from onsite sources

Arsenic Results in OUs 5 and 6

The arsenic results from environmental samples collected from OUs 5 and 6 are presented by medium in Table 1 and as follows

Surface Soil, Subsurface Soil, and Surface Water Arsenic was not listed as a PCOC for any of these media in either OU5 or OU6

Groundwater Initially, OU6 omitted total arsenic as a PCOC in groundwater samples using professional judgment, based primarily on the correlation between elevated metals concentrations and total suspended solids Although EPA thought that this rationale "appears generally sound," they requested that DOE retain arsenic (as well as three other metals) as a COC in groundwater based on the fact that the maximum OU6 concentration is 18 μg/l and the PRG is 0 0038 μg/l DOE agreed to handle this issue for OU6 in the same way as OU2 OU2 had received conditional approval on their COC TM with the understanding that a quantitative risk assessment will be conducted for arsenic in groundwater and the results included in the uncertainty analysis (rather than in the risk characterization) section of the HHRA The risk from these metals, including arsenic, would not be added in with the risks from the other groundwater COCs

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the very small sample size for the OU data (n=8 for OU5, n=15 for OU6), and the large number of nondetects in the background arsenic data, the results of the Gehan test, evaluated below, need to be evaluated carefully

The attached RFETS maps show the distribution of arsenic in stream sediments, pond sediments, and surface soils onsite and expanded offsite to include the OU3 reservoirs The various color codes and values shown in the legend are the $UTLs_{99/99}$ for these specific media 10 1 mg/kg for stream sediments, 12 9 mg/kg for surface soils, and 66 7 mg/kg for pond sediments

Evaluation of Gehan Statistical Test

EG&G examined the statistical comparison of the OUs 5 and 6 stream sediment results to background For stream sediments, as well as other media, the one test that was predominantly failed was the Gehan test Although the Gehan test was proposed as a way to deal with multiple detection limits and is not supposed to be sensitive to sample size or number of nondetects, there is some concern regarding the validity of this statistical test when comparing data sets with small sample sizes or a large percentage of nondetects

Helsel (1990) notes that, "In the most comprehensive review of these score tests (such as the Gehan), most of them were found inappropriate for the case of unequal sample sizes "(See Attachment A) Gilbert himself cautioned us about the use of the untested and unproven Gehan test Gilbert (1993) noted "As the performance of the Gehan test has not, in my opinion, been adequately determined, I recommend that statistical evaluations and comparisons of its performance with competing tests should be conducted by EG&G at the earliest time " Competing tests include the Wilcoxon Rank Sum and Kruskal-Wallis tests, which, according to Gilbert " are very well known by statisticians and practitioners, and are widely used in many fields of application" (Attachment B)

An evaluation of Gilbert's recommendations, including comparative testing of the Gehan test, was prepared by Dr Kenny S Crump, ICF Kaiser, at the request of EG&G Rocky Flats Dr Crump (1993) states as one of his conclusions that "For data containing nondetects, Gilbert recommends the *ad hoc* approach of applying the slippage and quantile tests to the ranks calculated in connection with the Gehan test rather than to the actual data This *ad hoc* procedure is invalid and can produce nonsensical results Consequently, **it should not be applied under any conditions** "

Weight of Evidence

Attachment C provides a series of tables showing the ranges of arsenic in rocks, surface soils, and sediments It should be noted that "the northern and southern parts of the (Front Range) Corridor are underlain by marine shale, which typically contain larger amounts of trace elements " (Severson and Tourtelot, 1994) As seen in these tables, the values of arsenic the very small sample size for the OU data (n=8 for OU5, n=15 for OU6), and the large number of nondetects in the background arsenic data, the results of the Gehan test, evaluated below, need to be evaluated carefully

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Table 1

SUMMARY OF ARSENIC DATA FOR OU5 AND OU6				
	OU5 Results		OU6 Results	
Medium	Mean	Maximum	Mean	Maximum
Surface Soil (mg/kg)	4 6	8 9	5 3	11 0
Subsurface Soil (mg/kg)	3 9	18 9	3 6	10 9
UHSU Groundwater - total (ug/l)	5 6	13 3	4 6	18 0
UHSU Groundwater - dissolved (ug/l)	4 1	8 1	3 9	4 0
Surface Water - total (ug/l)	4 4	5 7	4 7	6 6
Surface Water - dissolved (ug/l)	4 8*	3 6	4 8	7 4
Seep Water - total (ug/l)	10U	10U	NA	NA
Seep Water - dissolved (ug/l)	NA	NA	NA	NA
Pond Sediments (mg/kg)	5 5	9 8	6 0	10 2
Seep Sediments (mg/kg)	5 7	6 5	NA	NA
Stream Sediments (mg/kg)	3 5	5 5	3 6	5 8

U = Not detected

NA = Samples not taken in this medium

* = This data set contained many nondetects The highest detected value was 3 6 ug/l Calculating the mean using 1/2 the detection limit of 10 ug/l resulted in a mean higher than the maximum concentration

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Surface Water - total (ug/l)	4 4	5 7	4 7	6 6
Surface Water - dissolved (ug/l)	4 8*	3 6	4 8	7 4
Seep Water - total (ug/l)	10U	10U	NA	NA
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o knowledge below the reporting limit Results do not depend on a distribution al assumption (25)

When severe censoring (near 50% or more) occurs all of the above tests have little power to detect differences in central values The investigator will find it difficult to state conclusions about the relative magnitudes of central values and other characteristics must be compared For instance contingency tables (class 3) can test for a difference in the proportion of data above the reporting limit in each group (20) This test can be used when the data are reported only as detected or not detected It also may be used when response data can be categorized into three or more groups such as below detection detected but below some health standard and exceeding standards The test determines whether the proportion of data falling into each response category differs as a function of different explanatory groups such as different sites or land use categories

Hypothesis testing with multiple reporting limits More than one reporting limit often is present in environmental data When this occurs hypothesis tests such as comparisons between data groups are greatly complicated The fabrication of data followed by computation of *t* tests or similar parametric procedures is at least as arbitrary with multiple reporting limits as with one reporting limit and should be avoided Also data below all reporting limits should never be deleted before testing

Tobit regression (class 2) can be used with multiple reporting limits Data should have a normal distribution around all group means and equal group variances to use the test These assumptions are difficult to verify with censored data especially for small data sets

One robust method that always can be used is to censor all data at the highest reporting limit and then perform the appropriate nonparametric test Thus the data set

<1 <1 <1 5 7 8 <10 <10 <10 12 16 25

would become

<10 <10 <10 <10 <10 <10 <10 <10 <10 12 16 25

and a rank-sum test would be performed to compare this with another data set Clearly this causes a loss of information which may be severe enough to obscure actual differences between groups (a loss of power) For some situations however this is the best that can be done

Alternatively nonparametric score tests common in the medical survival analysis literature sometimes can be applied to the case of multiple reporting limits (26) These tests modify uncensored rank test statistics to compare groups of data The modifications allow for the presence of multiple reporting limits In the most comprehensive review of these score tests (27) most of them were found inappropriate for the case of unequal sample sizes Another crucial assumption of score tests is that the censoring mechanism must be independent of the effect under investigation (see box) Unfortunately this often is not the case with environmental data The Peto–Prentice test with an asymptotic variance estimate was found to be the least sensitive to unequal sample sizes and to differing censoring mechanisms (27)

In summary robust hypothesis tests have several advantages over their distributional counterparts when they are applied to censored data These advantages include freedom from adherence to a normal distribution greater power for the skewed distributions common to environmental data comparisons between central values such as the median rather than the mean and the incorporation of data below the reporting limit without fabrication of values or bias Information contained in less-than values is used accurately and does not misrepresent the state of that information

When adherence to a normal distribution can be documented tobit regression (class 2) offers the ability to incorporate multiple reporting limits regardless of a change in censoring mechanism Score tests (class 3) require consistency in the censoring mechanism with respect to the effect being tested

Methods for regression

With censored data the use of ordinary least squares (OLS) for regression is prohibited Coefficients for slopes and intercept cannot be computed without values for the censored observations and substituting fabricated values may produce coefficients strongly dependent on the values substituted Four alternative methods capable of incorporating censored observations are described below The first and last approaches Kendall s robust fit (28) and contingency tables (20) are nonparametric (class 3) methods requiring no distributional assumptions Robust correlation coefficients also are mentioned (20) Tobit and logistic regression (24 29) the second and third methods fit lines to data using maximum likelihood (class 2) Both methods assume normality of the residuals though with logistic regression the assumption is after a logit

The appropriateness of score tests

When a score test is not appropriate

Score tests are inappropriate when the censoring mechanism differs for the two groups That is, the probability of obtaining a value below a given reporting limit differs for the two groups when the null hypothesis that the groups are identical is true

1 Suppose a trend over time is being investigated The first five years of data are produced by a method that has a reporting limit of 10 µg/L, the second five years of data are compiled by an improved method with 1 µg/L as its reporting limit A score test of the first half of the data versus the second would not be valid because the censoring mechanism itself varies as a direct function of time

2 Two groups of data are compared as in a rank-sum test, but most of the data from group A were measured with a chemical method having 1 as its reporting limit and most of group B were measured with a method having 10 as its reporting limit A score test would not yield valid results because the censoring mechanism varies as a function of what is being investigated (the two groups)

When a score test is appropriate

A score test yields valid results when the change in censoring mechanism is not related to the effect being measured Stated another way, the probability of obtaining data below each reporting limit is the same for all groups, assuming that the null hypothesis of no trend or no difference is true Here a score test provides much greater power than does artificially censoring all data below the highest reporting limit before using the rank-sum test

1 Comparisons have been made between two groups of data collected at roughly the same time and analyzed by the same methods, even though those methods and reporting limits have changed over time Score tests are valid in this case

2 Differing reporting limits result from analyses performed at different laboratories but each sample had been assigned at random to the different laboratories Censoring thus is not a function of what is being tested but is a random effect and score tests would be valid

ATTACHMENT A - HELSEL, 1990

Gilbert's report

Battelle

replacement of non-detects, testing for distribution shape and variance, and conducting appropriate t tests or the WRS test.

As the performance of the Gehan test has not, in my opinion, been adequately determined, I recommend that statistical evaluations and comparisons of its performance with competing tests should be conducted by EG&G at the earliest time. The performance assessments should specifically include data sets that contain one or more nondetects larger than detects The performance of the Gehan test (or any other test) for this situation has not, to my knowledge, been studied. More generally, future work should include considering how to statistically analyze data sets that contain nondetects that are larger than all detects

Example: We use the RFP data in Figure 1 and a Type I error rate of 0 05 In Figure 7 the ordered background and OU data as well as their Gehan ranks and scores are displayed. Using these scores [$a(R_i)$] and m = 10, n = 20, N = 30 in the equation for Z, we find that Z = -0.7376 Since Z is smaller than 1.645, we conclude that Gehan's test does not indicate the analyte is a PCOC.

Test 6. t test

Purpose The t test is one of the most widely known statistical tests for testing that the means of two populations are different When the background and OU data are normally and independently distributed, each distribution has the same variance, and neither data set contains any nondetects, the t test is the preferred test

Method: The reader is referred to a statistics book for how to conduct a t test, e g , Snedecor and Cochran (1980, pp 89-99)

Example: We use the RFP data in Figure 1 However, the t test is not recommended because some OU data are nondetects The Gehan test should be used instead because nondetects with multiple detection limits are present If no nondetects were present then the WRS test is appropriate

Summary Comments for PHASE IV

The tests discussed above have been applied to the data in Figure 1. We found that the HM comparisons identified 2 OU measurements that exceeded the 95% UTL on the 95th percentile. However, the Slippage, Quantile and Gehan tests did not indicate the analyte is a PCOC The next step is to apply professional judgment, geochemical analyses, and knowledge of RFP (Phase V) to evaluate the validity of the individual measurements and the results of the statistical tests (These checks supplement the data validity checks made during Phase 2 (data collection/validation.) If uncertainty remains after this evaluation,

ATTACHMENT C - LITERATURE REVIEW

ITS

ON)

awater

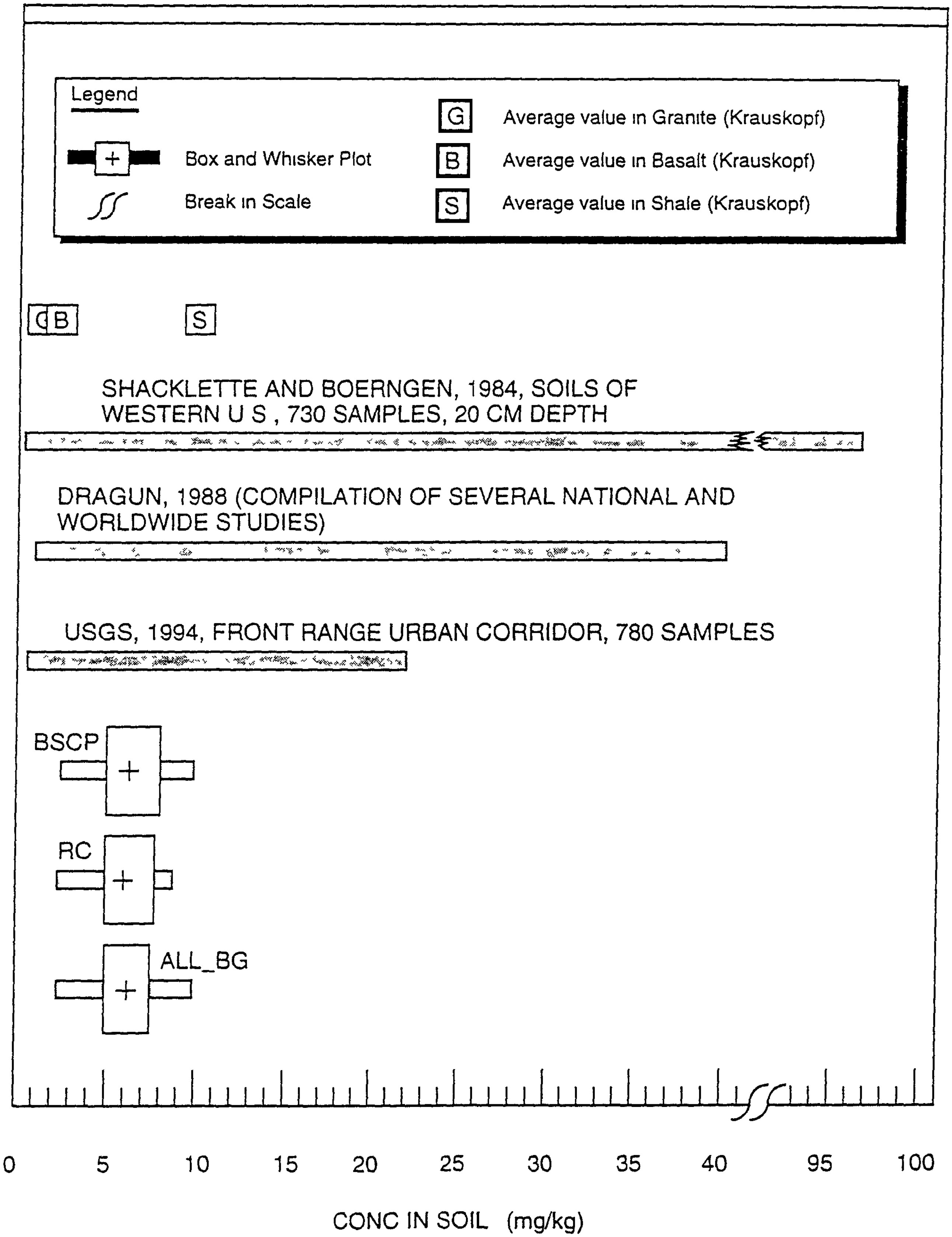
0 000
2
0 002
0 002
412
0 770
1 290
350
0 001
0 000
0 06
2×10^{-4}
1 3
0 02
8 0
905
28
3×10^{-5}
18 800

Element	Crust	Granite	Basalt	Shale	Sea ater
V	110	50	250	130	0 0025
Cr	100	20	200	100	3×10^{-4}
Rb	90	150	30	140	0 12
Ni	75	0 8	150	80	0 0017
Zn	70	50	100	90	0 0049
Ce	70	90	30	70	1×10^{-6}
Cu	50	12	100	50	5×10^{-4}
Y	35	40	30	35	1×10^{-6}
La	35	55	10	40	3×10^{-6}
Nd	30	35	20	30	3×10^{-6}
Co	22	3	48	20	5×10^{-5}
Li	20	30	12	60	0 18
N	20	20	20	60	150
Sc	20	8	35	15	6×10^{-7}
Nb	20	20	20	15	1×10^{-5}
Ga	18	18	18	25	3×10^{-5}
Pb	12 5	20	3 5	20	3×10^{-5}
B	10	15	5	100	4 4
Th	8 5	20	1 5	12	1×10^{-5}
Pr	8	10	4	9	6×10^{-7}
Sm	7	9	5	7	5×10^{-8}
Gd	7	8	6	6	7×10^{-7}
Dy	6	6 5	4	5	9×10^{-7}
Er	3 5	4 5	3	3 5	8×10^{-7}
Yb	3 5	4	2 5	3 5	8×10^{-7}
Be	3	5	0 5	3	6×10^{-7}
Cs	3	5	1	7	4×10^{-4}
Hf	3	4	1 5	4	7×10^{-6}
U	2 7	5	0 5	3 5	0 0032
Br	2 5	0 5	0 5	5	67
Sn	2 5	3	2	6	1×10^{-5}
Ta	2	3 5	1	2	2×10^{-6}
As	1 8	1 5	2	10	0 0037
Ge	1 5	1 5	1 5	1 5	5×10^{-5}
Mo	1 5	1 5	1	2	0 01
Ho	1 5	2	1	1 5	2×10^{-7}
Eu	1 2	1 0	1 5	1 4	1×10^{-8}
W	1 2	1 5	0 8	1 8	1×10^{-4}
Tb	1	1 5	0 8	1	1×10^{-7}
Tl	0 8	1 2	0 2	1	1×10^{-5}
Lu	0 6	0 7	0 5	0 6	2×10^{-7}
Tm	0 5	0 6	0 5	0 6	2×10^{-7}
Sb	0 2	0 2	0 2	1 5	$2 4 \times 10^{-4}$
I	0 2	0 2	0 1	2	0 06
Cd	0 15	0 1	0 2	0 3	1×10^{-4}
Bi	0 15	0 2	0 1	0 2	2×10^{-5}
In	0 06	0 05	0 07	0 06	1×10^{-7}
Ag	0 07	0 04	0 1	0 1	4×10^{-5}
Se	0 05	0 05	0 05	0 6	2×10^{-4}
Hg	0 02	0 03	0 01	0 3	3×10^{-5}
Au	0 003	0 002	0 004	0 003	4×10^{-6}

Krauskopf, Konrad B , Introduction ot Geochemistry

ARSENIC

PROGRAMMATIC PRG = 3 66E-01



Source EG&G, 1995, Background Soils Characterization Project (BSCP) Presentation

Table 42 Elemental composition of the earth's crust and sediments (major cations in %, minor and trace elements μg/g)

Element	Mean crust[a]	Mean sediment[b]	Average shale[c]	Deep sea clay	Shallow water sediment[d]	River suspended sed.[e]	Sandstone[f]	Limestone[f]	Soil[h]
Silicon	27.7%	24.5%	27.5%	25.0%	25.0%	28.5%	32.7%	5.2%	33.0%
Aluminium	8.2%	7.2%	8.0%	8.4%	8.4%	9.4%	4.3%	0.7%	6.7%
Iron	4.1%	4.1%	4.7%	6.5%	6.5%	4.8%	2.9%	1.7%	3.2%
Calcium	4.1%	6.6%	2.2%	2.9%	2.9%	2.2%	3.1%	34.0%	2.0%
Magnesium	2.3%	1.4%	1.5%	2.1%	2.1%	1.2%	1.2%	0.6%	0.8%
Sodium	2.3%	0.6%	1.0%	4.0%	4.0%	0.7%	1.0%	0.1%	1.1%
Potassium	2.1%	2.0%	2.7%	2.5%	2.5%	2.0%	1.5%	0.3%	1.8%
Titanium	0.6%	0.4%	0.5%	0.5%	0.5%	0.6%	0.4%	0.03%	0.5%
Phosphorus	1 000	670	700	1 500	550	1 150	440	700	800
Manganese	950	770	850	6 700	850	1 050	460	620	760
Barium	500	460	580	2 300	–	600	320	90	568
Strontium	370	320	140	110	160	150	320	610	278
Zirconium	190	150	160	150	240	–	220	20	345
Vanadium	160	105	130	120	145	170	20	45	108
Chromium	100(?)	72	90	90	60	100	35	11	84
Nickel	80(?)	52	68	250	35	90	9	7	34
Zinc	75	95	95	165	92	350	30	20	60
Copper	50	33	45	250	56	100	30	5.1	26
Cobalt	20	14	19	74	13	20	0.3	0.1	12
Lithium	20	56	66	57	77	25	38	7.5	31
Scandium	16	10	13	19	12	18	1	1	10
Lead	14	19	20	80	22	150	10	5.7	29
Cesium	3.0	4.2	5	6	–	6	0.5	0.5	3
Beryllium	2.6	2	3	2.6	3	–	< 1	1	1.5
Uranium	2.4	3.1	3.7	1.3	–	3	0.5	2.2	2.2
Tin	2.2	4.6	6.0	1.5	2	–	0.5	0.5	5.8
Molybdenum	1.5	2.0	2.6	27	1	3	0.2	0.2	1.9
Arsenic	1.5	7.7	13	13[e]	5	5	1	1	11.3
Tungsten	1.0	1.7	1.8	1.1[e]	–	–	1.6	0.6	1.1
Antimony	0.2	1.2	1.5	1.0		2.5	0.05	0.3	1.7
Cadmium	0.11	0.17	0.22[g]	0.42	–	1	0.05	0.03	0.6
Silver	0.07	0.06	0.07	0.11	–	–	0.25	0.12	0.4
Mercury	0.05	0.19	0.18[g]	0.08	–	–	0.29	0.16	0.1
Selenium	0.05	0.42	0.06	0.17	–	–	< 0.01	< 0.03	0.4

[a] Bowen (1979)
[b] Bowen (1979) after Wedepohl (1968)
[c] Turekian and Wedepohl (1961)
[d] Wedepohl (1969 1978)
[e] Martin and Meybeck (1979)
[f] Bowen (1979) after Wedepohl (1968 1969 1974)
[g] Marowski and Wedepohl (1971)
[h] Ure and Berrow (1982)

Salomons, W and U Forstner, 1984, Metals in the Hydrocycle

Source Fowler, Bruce A , 1983, Biological and Environmental Effects of Arsenic

Arsenic fluxes between geochemical reservoirs [a]

Flux	Magnitude (10^8 g/yr)
Land to	
terrestrial biota	282 8
atmosphere (vapor)	210
atmosphere (continental dust)	25
ocean (river suspended)	2 380
ocean (river dissolved)	612
atmosphere (emission)	779 3
Atmosphere to	
land (rain)	970
land (dust)	8
ocean (rain)	1 970
ocean (dust)	17
Ocean to	
atmosphere	1 947 9
In ocean	
skeletal to sediments	29 4
dissolved to biota	1 080
biota to particulate	38 9
biota to dissolved	1 041 1
dissolved to skeletal	344 5
skeletal to dissolved	315 1
particulate to sediment	2 435 9
Terrestrial	
biota to land	292 8
Volcanic to	
atmosphere (vapor)	0 1
atmosphere (dust)	2 7
sediments (oceanic)	40
land	54
Sediments to	
land	2 400
Mining	455

a Data from Mackenzie et al (1979)

Arsenic in rocks

Igneous rocks	No analyses	Arsenic concentration (ppm)	
		Range usually reported	Average
Ultrabasic	37	0 3 – 16	3 0
Basalts gabbros	146	0 06 – 113	2 0
Andesites dacites	41	0 5 – 5 8	2 0
Granitic	73	0 2 – 13 8	1 5
Silicic volcanic	52	0 2 – 12 2	3 0
Sedimentary			
Limestones	37	0 1 – 20	1 7
Sandstones	11	0 6 – 120	2 0
Shales and clays	324	0 3 – 490	14 5[b]
Phosphorites	282	0 4 – 188	22 6
Sedimentary iron ores	110	1 – 2 900	400
Sedimentary manganese ores	–	(up to 1 5%)	
Coal	1 150	0 – 2 000	13

a Estimated on the basis of data of Onishi (1969) and Boyle and Jonasson (1973)
b Excluding one sample with arsenic at 490 ppm
c Boyle and Jonasson (1973) gave 4 ppm

Arsenic concentrations in sediments and biota of freshwater ecosystems

Author	Location	Range of sediment arsenic concentrations (mg/kg)	Range of As concentrations in biota		
			plants		aquatic organisms
Tsai et al 1979	Baltimore Harbor U S A	13 – 229[a]	ND		ND
Reay 1972	Waikato River New Zealand	26 – 550[a]	8 – 971[a]	(plants)	ND
Lancaster et al 1971	Lake Arapuni Lake Ohakuri	ND	215 – 1 450	(lakeweed)	ND
Greichus et al 1978	Lake McIlwaine Zimbabwe	37[b]	2 9[b]	(plankton)	1 3 – 6[b] (oligachaetes benthic insects fish)
Price and Knight 1978	Lake Washington Mississippi and Sardis Reservoir U S A	2 99[a]	21 74	(plankton)	0 41 (clams)
Kobayashi and Lee 1978	Browns Lake Wisconsin U S A	4 – 307[b]	ND		ND
Heit et al 1980	Lake George New York U S A	3 1[b]	ND		0 2 – 0 3[b] (mussels)
Ruppert et al 1974	Chautauqua New York U S A	<0 5 – 306[b]	ND		ND
Wagemann et al 1978	Kam Lake Northwest Territories Canada	40 – 3 500[b]	250 – 920[b]	(plants)	0 – 820 (pelecypods oligodraetes ephemerophtera trichoptra chironomidae zooplankton hemiptera diptera hirudinea fish amphipoda)
Lucas et al 1970		ND	ND		
Pakkala et al 1972		ND	ND		

a Wet weight basis
b Dry weight basis
ND = not determined